Influence of skull modelling on conductivity estimation for EEG source analysis

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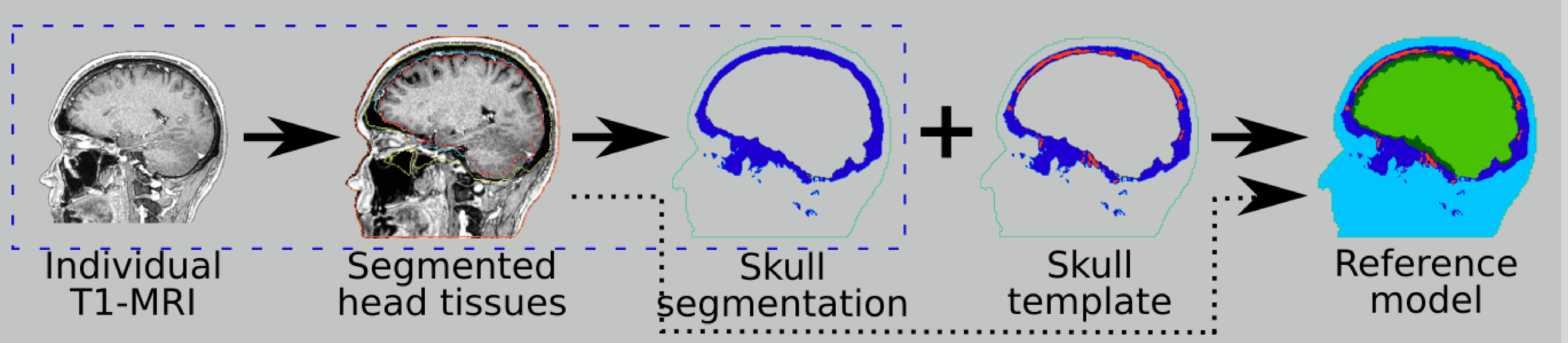
1. Introduction

The skull conductivity strongly influences the accuracy of EEG source localization methods [1]. As the conductivity of the skull has strong inter-individual variability, conductivity estimation techniques are required [2]. Typically, conductivity estimation is performed on data from a single event-related stimulation paradigm, which can be explained by one dipole source. A conductivity value for the skull can be estimated as the value for which the single dipole source provides the best goodness of fit to the data. This conductivity value is then used to analyse the actual data of interest. It is known that the optimal local skull conductivity when modelling the skull as one compartment depends on the amount of spongiosa present locally [3]. The research question arising is: Is conductivity estimation based on data from a single paradigm meaningful without accounting for the internal skull structure?

2. Materials and methods

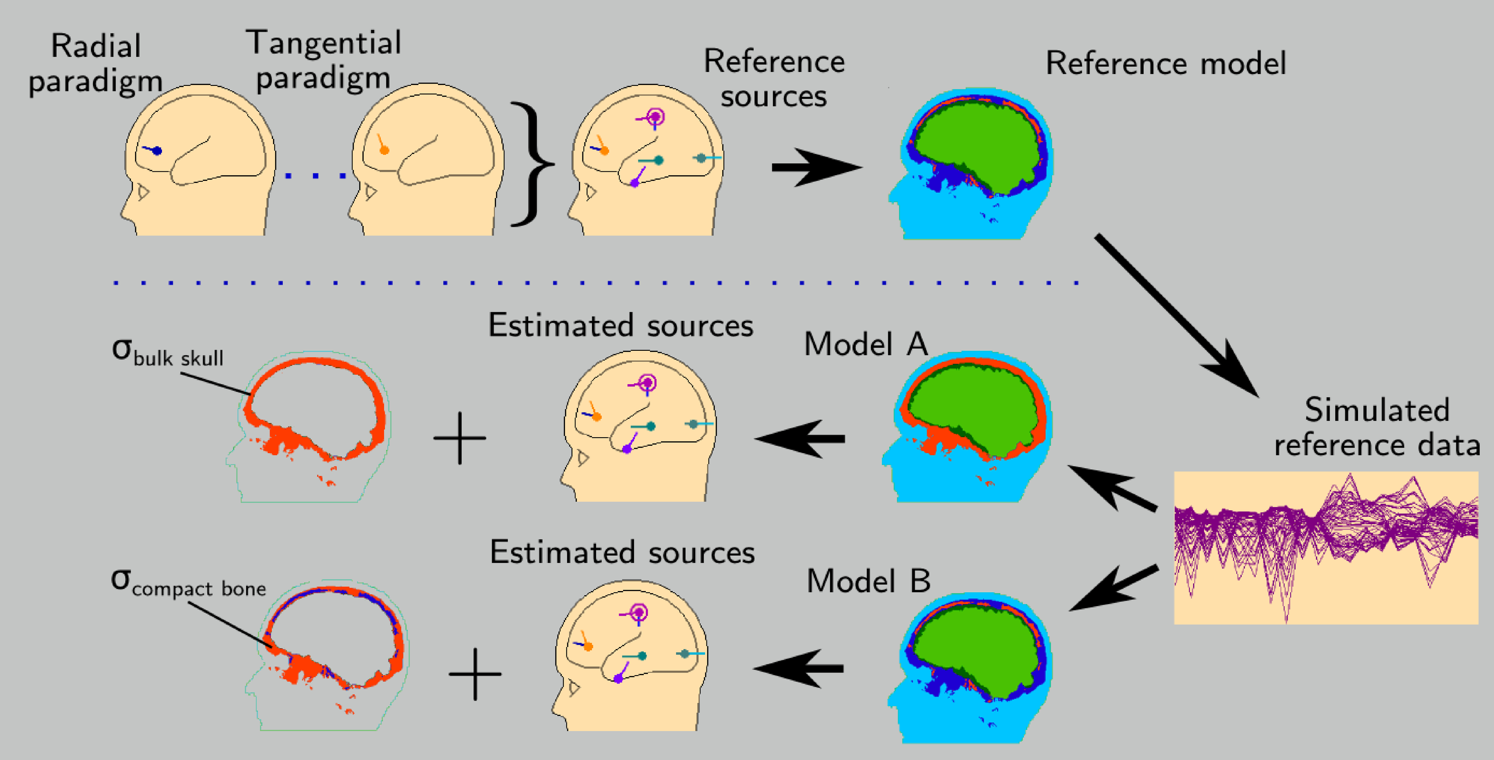
Reference model generation

- Segmentation [4] of individual T1 MRI of single subject.
  - No spongiosa segmentation possible due to low contrast and noise.
- Spongiosa model extraction from average high definition template (Colin 27 Average Brain) [5].
- Affine [6] and non-linear [7, 8] registration of skull template to individual skull segmentation.
- Post-processing of the transformed spongiosa using morphological operations to guarantee a smoother distribution and a minimum thickness of the inner and outer compact bone.
- Generation of $1\,\mathrm{mm}$ geometry-adapted hexahedral finite element mesh [9].



Simulation study

- Simulation of reference data for 20 sources at 10 different locations with radial and tangential orientations (mimicking different experimental paradigms).
- Derivations of two models from the reference model: model A with no spongiosa and model B with spongiosa.
- Conductivity estimation in both models and for all 20 paradigms using a simple exhaustive search approach for ...
  - ... bulk skull conductivity in model A.
  - ... compact bone conductivity in model B.
- Evaluation of the estimated conductivities and expected localization errors for both models using 1000 randomly selected probe sources.



3. Results

Simulation study

- The relative variability of the estimated conductivities is 77% higher when estimating the conductivity of the bulk skull (model A) as compared to the model accounting for the spongiosa (model B).

For the 1000 probe sources in model A:

- The difference between the maximum and the minimum mean localization error is $1.9\,\mathrm{mm}$.
- The expected mean source localization error ($6.05\,\mathrm{mm}$) is by $0.5\,\mathrm{mm}$ larger than the optimal error in the same model.

Error measures:

$$\text{Exp. mean loc. error} = \frac{\sum_i w_i e_i}{\sum_i w_i}$$

where e_i is the mean localization error across the 1000 probe sources for the i_{th} conductivity value while w_i is the number of times the i_{th} conductivity value was estimated based on our 20 reference sources.

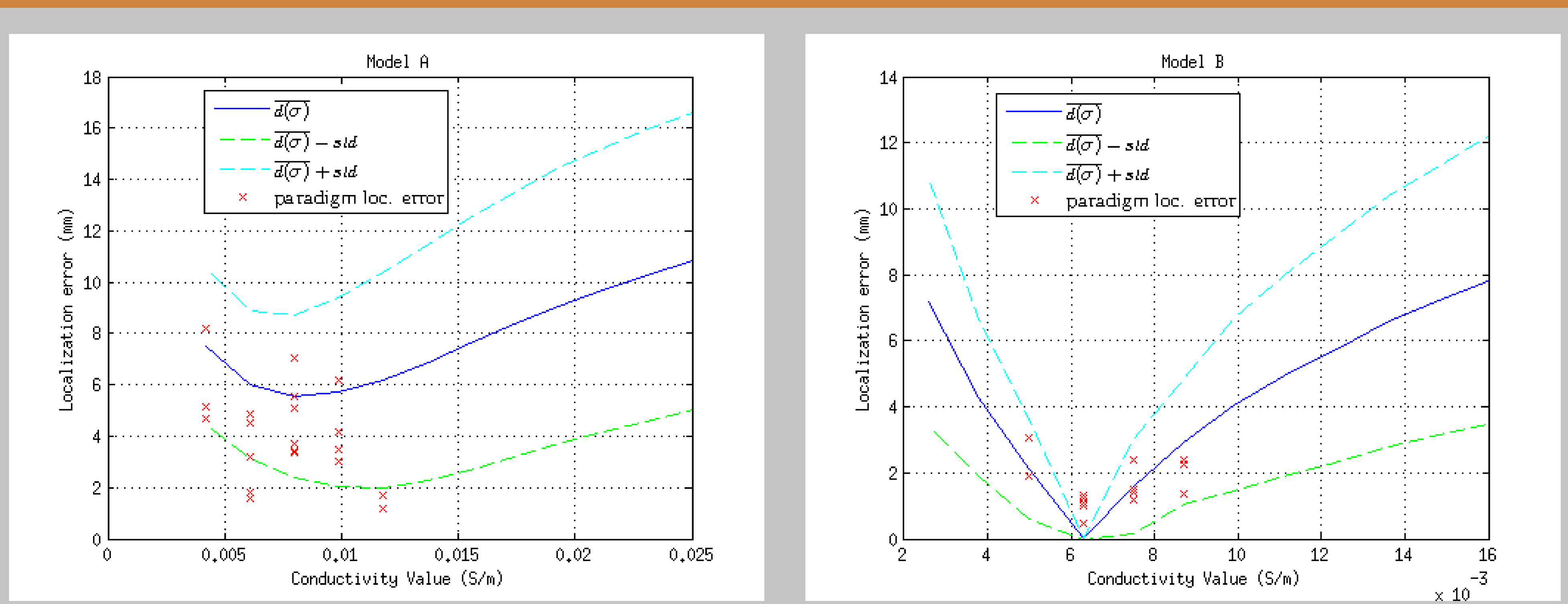


Figure 1 : Plot of localization errors across evenly spread conductivity values for the two test models. The red x symbols indicate the localization error for the 20 manually selected paradigms. The blue line indicates the mean localization errors for 1000 randomly placed sources.

4. Conclusion

Our results show that without accounting for the internal skull structure the conductivity estimation is not in all cases optimal. The estimated conductivity depends on the paradigm which data is used during the estimation process.

Acknowledgements

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References

[1] Vallaghé, S. & Clerc, M. A Global Sensitivity Analysis of Three- and Four-Layer EEG Conductivity Models. *IEEE Trans. Biomed. Eng.* 56, 988-995 (2009).

[2] Lew, S., Wolters, C. H., Anwander, A., Makeig, S. & MacLeod, R. S. Improved EEG source analysis using low-resolution conductivity estimation in a four-compartment finite element head model. *Hum. Brain Mapp.* 30, 2862-2878 (2009).

[3] Dannhauer, M., Lanfer, B., Wolters, C. H. & Knösche, T. R. Modeling of the human skull in EEG source analysis. *Hum. Brain Mapp.* 32, 1383-1399 (2011).

[4] BESA MRI, http://www.besa.de/products/besa-mri/besa-mri-overview/

[5] Holmes C. J., Hoge R., Collins L., Woods R., Toga A. W., & Evans A. C. Enhancement of MR images using registration for signal averaging. *J Comput Assist Tomogr.* 22 (2):324-33 (1998). http://dx.doi.org/10.1097/00004728-199803000-00032

[6] Jenkinson, M., Bannister, P., Brady, M. & Smith, S. Improved optimization for the robust and accurate linear registration and motion correction of brain images. *Neuroimage* 17, 825-841 (2002).

[7] ROI-Demons, http://darwin.bio.uci.edu/~cestark/roial/roial.html

[8] MedINRIA 1.x, http://www-sop.inria.fr/asclepios/software/MedINRIA/

[9] Wolters, C. H., Anwander, A., Berti, G. & Hartmann, U. Geometry-Adapted Hexahedral Meshes Improve Accuracy of Finite-Element-Method-Based EEG Source Analysis. *IEEE Transactions on Biomedical Engineering* 54, 1446-1453 (2007).